

Decision Support Tool for water remediation technologies assessment and selection

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Abstract

Water remediation operation involves consideration of several factors in relation to environmental, technological and socio-economic aspects. Hence, a decision support tool (DST) is necessary in order to manage problem complexity and to define effective water remediation interventions. CCR (Credence Clearwater Revival), a decision support tool for water remediation technologies assessment and selection, has been developed to help decision-makers (site owners, investors, local community representatives, environmentalists, regulators, etc.) to assess the available technologies and select the preferred remediation option. The analysis is based on technical, economical, environmental, and social criteria. These criteria are ranked by all involved parties to determine their relative importance for a particular water remediation project. The Multi-Criteria Decision Analysis (MCDA) is the core of the CCR using the PROMETHEE II algorithm.

Key words: decision support tool; multi-criteria decision analysis; water remediation.

Introduction

Decision-making on water management issues is often a process characterized by complexity, uncertainty, multiple and sometimes conflicting management objectives, as well as integration of numerous and different data types. For these reasons, it is important that policy-makers, engineers and the general public have proper information so that the current situation can be evaluated, trends identified, and ways can be found to a more sustainable future.

In environmental management, it has been shown that multi-criteria analysis can be effective in increasing the understanding, transparency, acceptability and robustness of a decision (Beinat; 2001). The aim of a multi-criteria problem is to lead to a concrete decision not an optimal solution, that is better than all other alternative for all the criteria (Utopia point) and leads to a mathematically ill-defined problem, but to find a compromise solution, i.e. an alternative that is better for most of the criteria (Vincke, 1992).

A variety of mature and emerging water remediation technologies is available and future trends in the water remediation industry will include continued competition among environmental service companies and technology developers, which will definitely result in further increase in the cleanup options. Consequently, the demand has developed for a decision support tool build on Multi Criteria Decision Analysis (MCDA) that could help the

decision makers to select the most appropriate technology for the specific contaminated water resource, before the costly remedial actions are taken.

The first prototype of CCR (Credence Clearwater Revival), a decision support tool for water remediation technologies assessment and selection, has been developed to improve decision-making ability of managers, investors, environmentalists and other stakeholders in developing countries by allowing faster or better decisions within the constraints of cognitive, time, regulatory and economic limits. CCR is Web-based decision support tool and will be accessible through Internet for target beneficiaries. The paper first presents the methodology used to develop CCR decision support tool. The second part presents a demonstration of the implemented prototype.

Generic framework of CCR

The generic framework of CCR was developed using WISE (Web-based Intelligent Systems Environment) that can easily be configured for a specific DSS. WISE represents a set of Java packages with specific organization and usage that could be freely and easily combined into a consistent whole, according to the specific problem at hand.

The following are the three main functional packages of WISE:

- WISE.ES – the package facilitating the development of conventional, rule-based expert systems in Java language.
- WISE.MCDM – the package facilitating the multi-criteria decision making process, offering the most widely used methods, PROMETHEE II.
- WISE.FUZZY – the package facilitating fuzzy sets, fuzzy production rules, and fuzzy linguistic functions (usually used together with WISE.ES package).

For the CCR decision support tool, the WISE.MCDM package represents the core module. The WISE.MCDM package facilitates the multi-criteria decision making process and implements the most popular MCDM algorithms of the “outranking” type PROMETEE II (Salminen *et al.*, 1998).

In order to support the decision-maker who must solve multicriteria problems, three kinds of methods were essentially considered - aggregation methods using utility functions, outranking methods and interactive methods. Outranking methods represent binary relations between alternatives, given the preference of the decision maker, the quality of the valuations of the alternatives and the nature of the problem (Vincke, 1992).

The approach of outranking methods is based on what Roy calls fundamental partial comparability axiom (Roy, 1990). According to this axiom, preferences can be modelled by means of four binary relations:

- (1) aPb; strict preference for one of the alternatives,
- (2) aQb weak preference for one alternative
- (3) aIb, indifference between the two alternatives
- (4) aJb, inability or refusal to compare the alternatives

Further, an alternative is preferred if aQb and not bQa , two alternatives are indifferent if aQb and bQa and two alternatives are incomparable if not aQb and not bQa .

Consequently, the dominant relation in outranking methods is poor, because it is assumed that an alternative a outranks an alternative b if a is at least as good as b on all the criteria, alternatively in most respects and not too much worse in any other respect considered (Vincke, 1992).

In PROMETHEE method, an outranking degree of each ordered pair of alternatives is computed. This value is processed having assigned weights to the criteria and translated into the preference of the decision maker, according to one of six functions $F_j(a,b)$: expressing, strict preference, indifference threshold, preference threshold. The final ranking of the alternatives is based on the increasing/decreasing number of the outranking degree. The PROMETHEE method does not take into account a discordance index between two alternatives. In this method, positive and negative outranking flows are applied to express how each alternative is outranking or outranked by all the parties. In the process of the complete ranking the alternatives are ranked with eventual ties, representing the dominance and degree of domination of each alternative.

The intersection of these flows yields a partial ranking, comparing the two preference flows, which is characterised by reflexive and transitive relations between two alternatives (aPb ; $bIc \rightarrow aPc$).

WISE.MCDM Package architecture

Using the WISE packages it is very easy to create the skeleton of every web based intelligent decision support tool. Figure 1 shows the core WISE-based DSS architecture used.

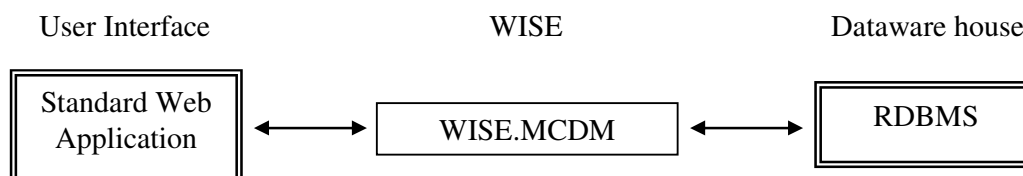


Figure 1: WISE based decision support tool architecture.

A concrete web based decision support tool consists of graphical user interface (GUI), central WISE layer and knowledge and data warehouse. GUI can be realized as Standard Web application which is realized using standard script languages (it is possible to use Java Server Pages and also Active Server Pages technologies with JavaScript and VBScript languages). *Structured query language* (SQL) has been chosen for the CCR decision support tool to support the *relational database management system* (RDBMS).

CCR structure

The CCR decision support tool is based solely on the information in the current version of the ICS-UNIDO compendium of wastewater treatment and water purification technologies (Buitrago *et al.*, 2002), based on compiling readily available information from the literature or

personal communications with involved technology owners/vendors/inventors. However, it could be easily extended in the future to reflect additional information acquired, and/or updates/revisions/additions to the ICS-UNIDO repository of best available technologies.

The CCR decision support tool has been designed and implemented over a Multi-Criteria Analysis system and utilizes a reference data-base in which water remediation technologies have been grouped in classes and categories according to their type of application (*in-situ* and *ex-situ*) and to the main mechanism involved in the process (physical, chemical, biological, thermal).

The first prototype of CCR includes 7 groups of established technologies (biological, physico-chemical and thermal), 8 target contaminants and 8 ranked criteria.

The structure of the data-base and the technologies available in the current stage of CCR decision support tool are shown in Table1. The target contaminants and criteria used for CCR decision support tool implementation are also indicated in Table1.

Table 1: List of available technologies, target contaminants and criteria used for CCR implementation

Available technologies	Target contaminants	Criteria
○ <i>Ex-situ</i> Biological Treatments	○ Nonhalogenated VOCs (Volatile Organic Compounds)	○ Overall cost
○ <i>Ex-situ</i> Physical/Chemical Treatments	○ Halogenated VOCs	○ Clean-up time
○ <i>Ex-situ</i> Thermal Treatments	○ Nonhalogenated SVOCs (Semi-Volatile Organic Compounds)	○ Reliability and maintainability
○ <i>In-situ</i> Biological Treatments	○ Halogenated SVOCs	○ Availability
○ <i>In-situ</i> Physical/Chemical Treatments	○ Fuels	○ Capital, operation and maintenance costs
○ <i>In-situ</i> Thermal Treatments	○ Explosives	○ Development status
○ Containment	○ Radionuclides	○ Stand alone character
	○ Inorganics	○ Residuals produced.

For the technology evaluation performed with CCR decision support tool, some criteria have been selected and a specific rating system has been developed. Each technology has then been rated according to its performance under each criterion.

Not all the stakeholders are equally interested in the criteria listed above. Investors are more interested in capital cost than the environmental acceptability of certain technology, while the local community and/or the environmentalists have exactly the opposite viewpoint. Therefore, the tool enables its user to select the subset of the criteria offered by the tool to be taken into account in particular MCDM session, as well as to put the relative weights to the chosen criteria that best reflect their specific preferences.

Demonstration prototype

The Software provides a repository of the best available water remediation technologies, a set of indicators for criteria for evaluating those technologies, and default values of weighting factors, that could be easily adjusted to suit the user's specific needs and preferences.

Besides, it is very easy to add a new technology or even a category of technologies, or change the parameters of the existing ones, or introduce new preference functions, etc. CCR is web-based application, so that our target beneficiaries from developing countries from all over the world, could easily access it, once they are properly authenticated. A stand-alone Java application of CCR is also available, In this case, the CCR application runs on MS Windows. MS Access 2000 database is used as a data repository. Before the CCR application can run, J2SE v 1.4.2 must be installed.

The software presents its users with a variety of configuration and input parameters from which to choose. Several are mandatory (such as identifying technologies to be evaluated), but there are many that the user can choose to leave blank or use the supplied default values. This way, the user decides how to tailor the analysis to satisfy his/her specific needs.

Multicriteria analysis of all the factors involved in the decision process determines whether a water remediation strategy is a feasible, effective and efficient solution and whether it satisfies all criteria and constraints defined by the user. Depending on the context in which water remediation technology assessment and selection is performed, the user can tailor a decision strategy balancing out various effectiveness and efficiency parameters, other criteria and constraints. From the user's point of view, the general algorithm for CCR decision support tool analysis is described in Figure 2.

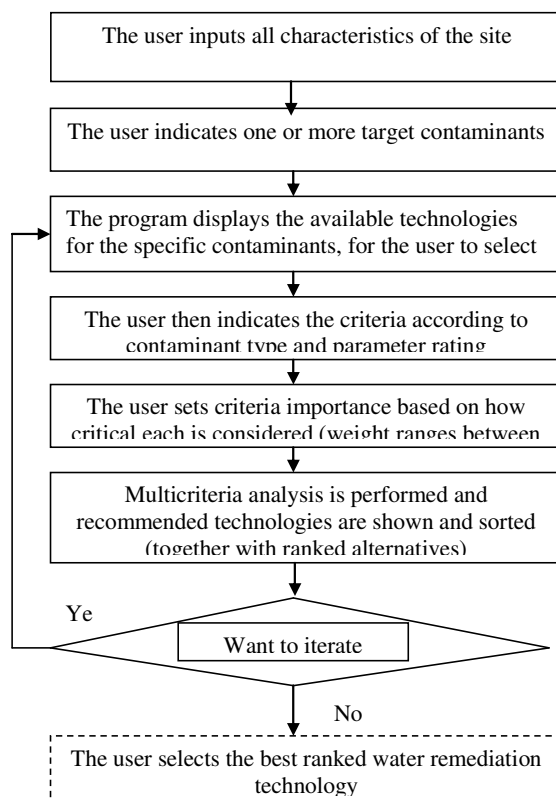


Figure . 2:. General algorithm supported with CCR.

CCR's user, after inputting data relevant to the project and the general site characteristics (e.g. name of the site, location, geographical coordinates, etc.), defines the contaminant (or a group of contaminants), uses a full set of technologies or indicates a subset of technologies in which there is interest and ranked criteria; indicates the criteria, preference functions (or use default functions chosen by the CCR developers) and corresponding weighting factors.

After the criteria are selected and their relative preferences set by the user, the multicriteria decision making process starts, and the system recommendation as well as ranked alternatives are presented to the user.

Figure 3 shows the application's main analysis window which consists of the current state of configuration, and a few dialogs for data entry purposes for creating a new project. It is connected to the database that contains previously entered information on available technologies and selection criteria; the database should be registered by the user and/or software administrator.

Figure 3: Main analysis window for the creation of a new water remediation project.

Figure 4: List of target contaminants to be indicated during analysis.

Dialogue boxes requesting the user to indicate the target contaminants to be removed and technologies to be simultaneously evaluated and compared are shown in Figure 4 and 5, respectively.

Figure 5: List of technologies to be selected during analysis.

Order	Technology	Net Flow
1	Natural Attenuation	0.2269504
2	Coagulation/Flocculation/Sedimentation	0.2198582
3	Deep Well Injection	0.1276596
4	Constructed Wetlands	0.08510638
5	Bioreactors	-0.3120567
6	Pyrolysis	-0.4680851

Figure 6: Multi-criteria analysis results.

A window *Set Criteria Importance* (not shown) is used to overview the values of all selected criteria for particular technology. A window *Multicriteria Analysis Results* (Figure 6) is used for the presentation of the results of the multicriteria analysis process.

Natural attenuation technology has been recommended as the most suitable option for a random selection of input parameters. This result, however, has to be exclusively intended as output from a test-phase of the system and not representing a real case of application.

Decision support systems can offer the dam reservoir manager the possibility to use updated information from the basin, and to plan and optimize long term and short term operation strategies. The integration of CCR within the decision support systems for dams operation and planning can allow the selection of the most appropriate technology particularly when the water is contaminated. The implementation of efficient and cost-effective remediation measures recommended by CCR in identified high-risk and high-priority hot spots in basin, aims at reducing the risk for catastrophic release and the introduction of contaminants into surface waters.

CCR has its limitations (e.g., it is unable to replicate some human decision making skills; may not match decision making's mode of expression...etc) and could not be used alone to reach an optimum selection. The compromise solution depends strongly on the decision maker's personality, on the circumstances of the decision aiding process, on the way the problem is presented and on the method, that is used (Vincke, 1992).

As Guariso and Werthner (1994) have already pointed out, environmental decision support system will not and cannot do the work that remains to be done by humans. Better computer support does not automatically imply a better decision. It is still the human's responsibility to be aware of the environmental situation in any particular situation and to cope with all the problems connected with it.

Conclusions

CCR decision support tool for water remediation technology assessment and selection, has been developed in ICS-UNIDO to help its target beneficiaries from developing countries in this sensitive decision making process. It is a Web-based decision support tool that allows assessment of the available water remediation technologies against various technical, environmental, financial and social criteria, and selection of the most suitable technology according to the specific objectives and preferences of a particular user/stakeholder. The demonstration prototype is currently being completed and is a subject to internal validation by means of test-runs utilising data gathered from assessed full-scale applications and verification process before being posted on the web for wider testing by beneficiary institution and/or individuals. Further work is being undertaken to split the list of contaminants and criteria to extend the use of CCR in order to evaluate wastewater treatment and water purification technologies.

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